

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

AUGUST, 1954



COMPARATIVE BEHAVIOR OF BOLTED AND RIVETED JOINTS

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STRUCTURAL DIVISION

{Discussion open until December 1, 1954}

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Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE \$0.50 PER COPY

EXPLANATORY STATEMENT

Practices in the design of riveted and bolted joints have developed largely from experience and have not always been supported by conclusive experimental data. With this fact in mind, twelve sponsoring organizations instituted the Research Council on Riveted and Bolted Structural Joints, in 1947.

Important among the projects of the Research Council is the study of high-strength bolts in structural joints. The high-strength bolt is a comparatively new type of structural fastener, and its use combines the field economies of bolts with strength greater than that of rivets.

At the Centennial Convention of the ASCE at Chicago, Ill., in 1952, a group of papers were presented describing research that had been done in the field of structural joints, with particular emphasis on study of the high-strength bolt.

These papers are currently being published as Proceedings-Separates and will be distributed over a period of several months beginning in May, 1954. Later, they will be gathered to form a single symposium in the Transactions of the ASCE. The six papers in this group are as follows:

"The Work of the Research Council on Riveted and Bolted Joints," by W. C. Stewart;

"Laboratory Tests of High-Tensile Bolted Structural Joints," by W. H. Munse, J.M. ASCE, D. T. Wright, and N. M. Newmark, M. ASCE;

"Comparative Behavior of Bolted and Riveted Joints," by Frank Baron, M. ASCE, and Edward W. Larson, Jr., J.M. ASCE;

"Slip Under Static Loads of Joints With High-Tensile Bolts," by R. A. Hechtman, A.M. ASCE, D. R. Young, and A. G. Chin and E. R. Savikko, Junior Members, ASCE;

"Fatigue in Riveted and Bolted Single-Lap Joints," by J. W. Carter and K. H. Lenzen, Associate Members, ASCE, and L. T. Wyly, M. ASCE;

"Structural Application of High-Strength Bolts," by T. R. Higgins and E. J. Ruble, Members, ASCE."

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N.Y.

COMPARATIVE BEHAVIOR OF BOLTED AND RIVETED JOINTS

Frank Baron,¹ M. ASCE and Edward W. Larson, Jr.,² J.M. ASCE

SYNOPSIS

A comparison is made of the behavior of bolted and riveted joints subjected to static and fatigue loads. The comparison is based on tests conducted of butt joints having a tension: shear: bearing ratio of about 1.00: 0.75: 1.50. The fasteners consisted of hot-driven rivets, cold-driven rivets, and high-strength bolts. Several lengths of grip were considered for each type of fastener. A group of butt joints fastened with high-strength rivets and having a tension: shear: bearing ratio of 1.00: 1.26: 1.83 was also considered.

The clamping force of a fastener was one of the most important factors affecting the fatigue strength of a joint. The fatigue strengths of the bolted joints were greater than those of the riveted joints. For static loads, the plate efficiencies were about the same irrespective of the kind of fastener. Efficiencies greater than 80 per cent were realized.

INTRODUCTION

The introduction of various kinds of fasteners, high-strength structural steels, and changes in fabrication procedures has raised questions concerning the comparative behavior of riveted and bolted joints subjected to static and fatigue loads. Ordinary structural steel rivets, ASTM-A141, are the most common types of fasteners used for connecting structural steel members. The use of high-strength structural steels at times warrants the use of high-strength rivets. The substitution of high-strength rivets, ASTM-A195, for ordinary rivets permits a reduction to be made in the number of rivets required in a joint or splice. The ASTM-A195 rivet has a high-strength but is frequently difficult to drive because of a low ductility. For ordinary lengths of grip the ASTM-A195 rivet usually has a lower clamping force than the ASTM-A141 rivet. Consequently, joints fastened with ASTM-A195 rivets may have objectionable slippages and low fatigue strengths.

The procedure of cold-driving of rivets has become a standard shop practice with several large fabricators. The advantages of cold-driving are frequently related to possible economies in money and time required

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for fabrication. Cold-driven rivets are known to have low values of clamping force but are expected to have a good degree of hole-filling. Consequently, the static and fatigue properties of joints with cold-driven rivets may be appreciably different from those of joints fastened with hot-driven rivets.

A procedure commonly used during erection consists of initially bolting up an entire structure or part of a structure and then replacing the bolts with rivets. Many engineers have felt that high-strength bolts, torqued to a high initial tension, could be used for a final assembly as well as for the initial assembly of a structure. However, other engineers have felt that bolts would loosen in service, and that the loosening could cause objectionable movements and a lowering in the fatigue strengths of the members.

At the time the Research Council on Riveted and Bolted Structural Joints was formed, very little was known concerning the behavior of joints fastened with cold-driven rivets or with high-tensile bolts. The literature principally dealt with the behavior of joints fastened with hot-driven rivets. This literature was extensive and is reviewed in the bibliography prepared by A. E. Richard de Jonge.³ In 1838, William Fairbairn⁴ reported the results of an extensive series of tests of riveted joints. Since then, many investigators have interested themselves in the behavior of riveted joints subjected to static loads. In 1938, W. M. Wilson and F. P. Thomas⁵ reported the results of fatigue tests made in connection with the construction of the San Francisco-Oakland Bay Bridge, California. In connection with the same structure, a series of static tension tests of riveted joints were conducted by Davis, Woodruff, and Davis.⁶ The variables considered in the latter series of tests were the length and type of joint, kind of plate steel, kind of rivet steel, and rivet pattern. Hot-driven rivets of carbon steel and of manganese steel were used in fabricating the joints. The behavior in static tension of riveted joints fastened with high-strength rivets was reported in 1942 by Jonathan Jones.⁷ In 1949, K. H. Lenzen⁸

3. de Jonge, A. E. Richard, "Riveted Joints" American Society of Mechanical Engineers, New York, 1945.
4. Fairbairn, William, "Experimental Inquiry into the Strength of Wrought Iron Plates and Their Riveted Joints as Applied to Ship Building and Vessels Exposed to Severe Strains", Philosophical Transactions, Royal Society, London, vol. 140 (1850), p. 677.
5. Wilson, W. M. and Thomas, F. P., "Fatigue Tests of Riveted Joints" Bulletin No. 302, University of Illinois, Engineering Experiment Station, vol. 31, 1938.
6. Davis, R. E., Woodruff, G. B. and Davis, H. E., "Tension Tests of Large Riveted Joints" Transactions - A. S. C. E., vol. 105 (1940), p. 1193.
7. "Physical Properties of Driven and Undriven Rivets of High-Strength Structural Steels," Progress Report of the Committee of the Structural Division on Structural Alloys. Proceedings, A. S. C. E., May, 1942, pp. 751-773.
8. Lenzen, K. H., "The Effect of Various Fasteners on the Fatigue Strength of a Structural Joint," A. R. E. A., Bulletin 480, Vol. 51, June-July, 1949.

reported the results of an investigation limited to obtaining a comparison of the fatigue strength of riveted and bolted structural joints having a grip of about 1 1/2 in. At this grip, the fatigue strengths for reversed cycles of loading were greater for the bolted joints than for the riveted joints.

In 1947, a project committee of the Research Council on Riveted and Bolted Structural Joints was assigned the task of determining the effect of grip on the fatigue strength of riveted and bolted structural joints. Double-butt joints having a tension: shear: bearing ratio of about 1.00: 0.75: 1.50 were designed for testing in static tension and in fatigue. The fasteners consisted of ASTM-A141 hot-driven rivets, ASTM-A141 cold-driven rivets, and ASTM-A325 high-strength bolts. At about the same time the latter program was begun, an alloy rivet steel meeting the strength requirements of the ASTM-A195 specification was brought to the attention of the writers. Preliminary tests indicated that rivets of the alloy steel were as easy to drive, were as ductile, and had the same degree of hole-filling as rivets of ordinary ASTM-A141 rivet steel. In addition, rivets of the alloy steel had a higher clamping force than rivets of ordinary carbon steel. Three series of butt joints were designed to compare the static and fatigue properties of joints fastened with the alloy steel rivets and with ordinary carbon steel rivets.

Description of Specimens

The dimensions and details of the various specimens tested in static tension and in fatigue are shown in Figure 1. Series A was fabricated by a single large fabricator and included four types of fasteners. These fasteners were hot-driven rivets, cold-formed cold-driven rivets, hot-formed cold-driven rivets, and high-strength bolts. Series B was fabricated by another large fabricator and included specimens fastened only with hot-formed cold-driven rivets. The lengths of grip considered for both series were 1 3/16 in., 2 1/16 in., and 3 1/16 in. The butt-joints of Series A and B had a tension: shear: bearing ratio of about 1.00: 0.75: 1.50. The rivets of both series were of ASTM-A141 steel. The bolted joints of Series A were assembled in the laboratory with high tensile bolts meeting the requirements of the ASTM-A325 specification. The assembly was made in accordance with a tentative specification which was later modified and approved⁹ by the Research Council on Riveted and Bolted Structural Joints. In general, the bolts were torqued to a value of 280 ft. lb. as compared to the value of 320 ft. lb. now recommended in the specification.

Two kinds of hot-driven rivets were used for the butt joints of Series C, D, and E. The rivets were of ASTM-A141 steel and of the alloy rivet

9. Specifications for Assembly of Structural Joints Using High Tensile Bolts, approved by Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, January 31, 1951. The specification was published by the American Railway Engineering Association, Bulletin 499, Vol. 53, 1952, and was endorsed by the American Institute of Steel Construction and by the Industrial Fasteners Institute.

steel which met the strength requirements of the ASTM-A195 specification. The joints of Series C and D had a tension: shear: bearing ratio of 1.00: 0.75: 1.51; whereas, the joints of Series E had a tension: shear: bearing ratio of 1:00: 1.26: 1.83. The lengths of grip for the joints of Series C and D were 1 5/16 in. and 4 1/16 in., respectively. Two lengths of grip, 1 13/16 in. and 2 15/16 in., were used for the joints of Series E.

The plates of each series were of ASTM-A7 steel and came from different heats and rolling. The surfaces of all series, except of Series C, were smooth and had the mill-scale left intact. The surfaces of Series C were rough and had a small amount of rust. The average physical properties for the main-plate materials of each series are given in Table 1.

The clamping stresses for various lengths of grip are given in Figure 2 for the different kinds of rivets. The clamping stresses were determined from measurements of the changes in grip caused by removing the plate materials from between the rivet heads. For the hot-driven rivets, the clamping stresses increased with length of grip. As compared to the clamping stresses of the ordinary carbon steel rivets, the clamping stress of the alloy steel rivets was about the same as a 1 inch grip and was appreciably greater at a 4 in. grip. For the cold-driven rivets, the clamping stresses decreased with length of grip and were small except for the specimens of Series B having a 1 3/16 in. grip.

As a result of difficulties encountered in conducting the fatigue tests of the cold-driven specimens of Series A, a survey was made to determine the degree of hole-filling that may exist in joints fabricated with cold-driven rivets. The survey was made of the butt joints of Series A and of sample specimens prepared by four large fabricators. The specimens were sawed through the rivets and then ground and polished. The gaps between each rivet and the plates were measured to a thousandth of an inch. A poor degree of hole-filling was obtained in the butt-joints of Series A and in most of the sample specimens. Only one fabricator demonstrated that a good degree of hole-filling can be obtained with cold-driven rivets. Consequently, it was concluded that the butt joints of Series A were representative of usual cold-driving practice. Since the cold-driving procedure of one fabricator resulted in a good degree of hole-filling, this fabricator prepared the specimens for Series B.

Comparative Behavior in Fatigue

The fatigue tests were conducted in two 250,000 lb. capacity machines and in one 80,000 lb. capacity machine. Each type of joint of Series A and B was tested at a zero to +24,000 psi. range of stress. The results of these tests are summarized in Table 2. Other ranges of zero to tension cycles of loading and a fully reversed cycle of loading were also considered for the various joints of Series A and B. The results for the fully reversed cycle of loading are given in Table 3. Each type of joint of Series C, D, and E was tested at a zero to +27,000 psi. range of stress. The results of the latter tests are summarized in Table 4. The

joints of Series C, D, and E were also tested at other ranges of zero to tension cycles of loading. In Figures 3 and 4, a summary is given of the results obtained for the riveted joints subjected to the various zero to tension cycles of loading.

The fatigue strengths of the bolted joints were considerably greater than those of the riveted joints. Only one of the twelve bolted joints tested at a zero to +24,000 psi. range of stress failed before 3,000,000 cycles were applied. For the bolted joints, the average fatigue strength at 2,000,000 cycles of a zero to tension loading was slightly greater than 28,000 psi. The fatigue lives of bolted joints tested at a zero to +30,000 psi. range of stress were approximately the same as those of the bolted joints tested at a $\pm 16,000$ psi. range of stress. For each of the latter ranges of stress, the average fatigue lives of the bolted joints decreased with an increase in length of grip. The fatigue fractures of the bolted joints occurred in the main-plates and were either across a net-section or a gross-section as shown in Figure 5. The fatigue lives of the bolted-joints which failed might have been increased if the bolts had been torqued to a greater value than 280 ft. lb. Two joints, for which the bolts were tightened with a torque of 320 ft. lb. as recommended by the Research Council, were tested at a zero to +21,500 psi. range of stress and neither failed after 12,275,000 cycles of loading. Four joints, for which the bolt tensions exceeded the yield strengths of the bolts, were tested at a zero to +24,000 psi. range of stress and none of these joints failed after 3,000,000 cycles of loading.

The average clamping force per bolt decreased about 20 per cent during a fatigue test. The loss in clamping force was evidently not caused by the turning of a nut as no turning of a nut was observed. The slippage of a bolted joint during the first application of a desired test load was approximately equal to the specified clearance of the bolt holes. The succeeding cyclical slippages of the bolted joints were negligible and did not exceed two-thousandths of an inch.

The average fatigue strengths of the joints fastened with hot-driven rivets and tested at zero to tension cycles of loading increased with an increase in length of grip. The strengths for the cyclical tension loadings were in general agreement with the values of the clamping stresses obtained for the various lengths of grip. The average fatigue strengths of the joints with the alloy steel rivets having a $1 \frac{5}{16}$ in., grip were about the same as those of similar joints fastened with hot-driven rivets of carbon steel. However, at grips greater than $1 \frac{5}{16}$ in., the average fatigue strengths of the joints with the alloy steel rivets were appreciably greater than those of the joints with the ordinary carbon steel rivets. An increase in the shear: tension ratio of the joints with the alloy steel rivets resulted in decreases in the fatigue strengths of the joints. The decreases in the fatigue-strengths caused by the change in the shear: tension ratio were probably influenced by the relative amounts of load resisted by friction between plates and by the bearing of rivets. For the riveted joints of Series A tested at fully reversed cycles of loading, the average fatigue strengths decreased with an increase in length of grip.

The fatigue fractures of the joints with hot-driven rivets occurred at

the net-sections of the main-plates except for certain joints of Series E. Broken rivets were obtained in four joints of Series E having a $1\frac{13}{16}$ in. grip and a tension: shear: bearing ratio of 1.00: 1.26: 1.83. The cyclical slippages for the various series of joints with hot-driven rivets did not exceed 5/1000 in. for the zero to tension cycles of loading. The cyclical slippages of such joints were greater for the reversed cycles of loading than for the zero to tension cycles of loading.

The fatigue characteristics of the joints with cold-driven rivets differed from those of the joints with hot-driven rivets. At a $3\frac{1}{16}$ in. length of grip, the cold-driven rivets of Series A and B failed in flexural fatigue for each range of loading considered. The lowest range of loading considered was a zero to +20,000 psi. range of stress on the net-section. In many cases, the broken rivets could not be detected until the specimens were cut apart. The fatigue strengths of the cold-driven specimens having a $3\frac{1}{16}$ in. grip were appreciably less than those of the corresponding specimens with hot-driven rivets. The fatigue strengths for the specimens with cold-driven rivets having a $1\frac{13}{16}$ in. grip or a $2\frac{1}{16}$ in. grip were dependent upon the cold-driving procedure and at times were as large as those for the corresponding specimens with hot-driven rivets.

The cyclical slippages of the cold-driven specimens having a $3\frac{1}{16}$ in. grip were very large and for one specimen reached a value of 40/1000 in. These slippages were so large that it was not possible to adjust the machines for the desired loads. The slippages for the specimens with cold-driven rivets decreased with a decrease in grip and were in general greater than for the corresponding specimens with hot-driven rivets.

Comparative Behavior in Static Tension

The static tension tests of the various types of joints were made to determine the efficiencies, load-slip characteristics, and the shear stresses at which the first major slips occurred. The tests were made in a 1,000,000 lb. capacity Baldwin-Southwark testing machine. The load on a specimen was applied in increments until failure occurred either in the main-plate or in the rivets of a joint. If failure first occurred in the rivets, the broken rivets were removed and were replaced with high-tensile bolts. The specimen was then reloaded until failure occurred in the main-plate of a joint.

Typical examples of the load-slip relationships for the various joints are given in Figure 6. The plotted values of slip are the averages of the slip indicated by two dial gages. One gage on each edge of a joint was located at a section midway between the rows of fasteners of a joint. For the joints with hot-driven rivets and those with bolts, the load was initially resisted by friction between the plates until the friction was overcome and a sudden slip occurred. At this stage, the fasteners came into bearing. For the joints with cold-driven rivets, the fasteners in general were in bearing from the beginning of a test.

The shear stress at which the first major slip of a joint occurred depended on the type of fastener and length of grip. Average values of the

shear stresses at which the first major slips occurred for the joints with hot-driven rivets are given in Table 5. For the bolted joints tested in static tension and in fatigue, the first major slips occurred at a shear stress ranging between 9,000 psi. and 16,000 psi. The values for the bolted joints might have been greater if the bolts had been tightened with a greater torque than 280 ft. lb. The major slips for the bolted joints were of a different degree than those obtained for the riveted joints. This was due to the differences in the clearance for the driven rivets and for the bolts.

Apparent coefficients of friction were obtained for the joints with hot-driven rivets and for the bolted joints. The values of the coefficients for the joints with hot-driven rivets are given in Table 5 as ratios of the shear stresses at which the first major slips occurred to the initial clamping stresses of the rivets. The values of the ratios for the joints of Series C seem large. However, the plate surfaces of the latter joints were rough and had a small amount of rust. The values of the ratios for the bolted joints were small and were about 0.20.

The experimental efficiencies of the joints tested in static tension are summarized in Table 6. For each series of joints, the efficiencies were about the same irrespective of the kind of fastener and length of grip. In those cases for which bolts were used to replace broken rivets, the plate efficiencies apparently were not influenced by this procedure of testing. For all joints having drilled holes and a tension: shear: bearing ratio of about 1.00: 0.75: 1.50, the experimental efficiencies were about 82 per cent. The theoretical efficiency for the latter group of joints was about 75 per cent. The joints of Series C had punched holes and an experimental efficiency of about 71 per cent. The low efficiencies for the joints of Series C were the result of the holes being punched instead of being drilled. The joints having drilled holes and a tension: shear: bearing ratio of 1.00: 1.26: 1.83 had an experimental efficiency of about 86 per cent as compared to a theoretical efficiency of 77 per cent. All of the main-plate failures occurred at the first row of fasteners. The fractures were 100 per cent ductile for the joints of Series A to D and were 75 per cent ductile for the joints of Series E.

CONCLUSIONS

The following conclusions can be made concerning the comparative behavior of bolted and riveted joints subjected to static and fatigue loads:

1. The fatigue strengths of joints with high-tensile bolts are considerably greater than those of joints with hot-driven or cold-driven rivets. Although the clamping force of a joint with bolts somewhat decreases during a fatigue test, the nuts do not turn. The cyclical slippages of joints fastened with bolts are negligible; however, the slippage during the first application of a load can equal the clearance of the bolt holes. The substitution of high-tensile bolts for rivets does not change the plate efficiencies of a joint subjected to static loads. For joints having a 1/16 in. clearance for holes, the first major slip of a bolted joint is considerably greater than that of a riveted joint. The shear stress at which the first major slip of a joint occurs is dependent on

the clamping force, the degree of hole-filling, and the condition of the contact surfaces of the joint.

2. For zero to tension cycles of loading, the fatigue strengths of joints with hot-driven rivets increase with an increase in length of grip. The fatigue strengths of joints fastened with alloy steel rivets having larger clamping forces than ordinary steel rivets are greater than those of similar joints fastened with ordinary steel rivets. An increase in the shear: tension ratio of a joint fastened with hot-driven rivets can result in a decrease in the fatigue strength of the joint.
3. The fatigue strengths of a joint with cold-driven rivets having a long grip, such as $3 \frac{1}{16}$ in., are considerably less than those of similar joints with hot-driven rivets. At this length of grip, the cold-driven rivets will fail in fatigue. The fatigue strength of a joint with cold-driven rivets having a short grip can be as great as that of a similar joint with hot-driven rivets but is dependent on the cold-driving procedure. For fatigue cycles of loading, large slippages can and probably will occur for joints fastened with cold-driven rivets as the degree of hole-filling is dependent on the cold-driving procedure.

TABLE 1. AVERAGE PHYSICAL PROPERTIES OF THE MAIN-PLATE MATERIALS

Series	Yield Point (psi)	Ultimate Stress (psi)	Elongation		Reduction In Area %
			8 in. %	2 in. %	
A	37,900	65,900	29.9	54.0	60.2
B	36,400	63,200	27.6	50.8	57.6
C	33,000	63,000	25.5	50.0	56.0
D	36,000	64,200	26.4	49.5	55.6
E	31,900	63,200	32.0	56.2	56.2

TABLE 2. SUMMARY OF FATIGUE TESTS FOR SERIES A AND B
STRESS CYCLE: 0 TO 24, 000 PSI. TENSION

Type of Fastener	Spec. No.	Grip In.	Average Number of Cycles Applied	Maximum Cyclical Slip of a Spec.		Number of Main-Plate Failures In Joints	Number of Joints Tested
				Initial	Final		
Bolt	A1B	1-3/16	3,123,662 (a)	0.001	0.001	None	4
	A2B	2-1/16	3,092,094	0.001	0.002	None	4
	A3B	3-1/16	2,298,120	0.001	0.001	One	4
ASTM-A325 Hot-Driven Rivet	A1H	1-3/16	443,446	0.002	0.003	Two	4
	A2H	2-1/16	913,613	0.001	0.001	Three	4
	A3H	3-1/16	1,075,932	0.002	0.002	Three	4
Cold-Driven Rivet ASTM-A141	A1CC	1-3/16	589,819	0.002	0.002	Three	4
	A2CC	2-1/16	927,528	0.006	0.019	Three	4
	A3CC	3-1/16	590,148	0.017	0.040	Rivets Failed	4
	A1CH	1-3/16	1,465,678	0.002	0.006	Four	4
	A2CH	2-1/16	533,824	0.004	0.010	Four	4
	A3CH	3-1/16	908,238	0.015	0.034	Rivets Failed	4
	B1CH	1-3/16	979,411	0.002	0.003	Three	4
	B2CH	2-1/16	954,239	0.002	0.003	Two	2
	B3CH	3-1/16	483,472	0.004	0.009	Rivets Failed	4

(a) Bolts torqued to a value of 400 ft. lb. All other bolts torqued to a value of 280 ft. lb.

TABLE 3. SUMMARY OF FATIGUE TESTS FOR SERIES A
STRESS CYCLE: +16,000 TO -16,000 PSI.

Type of Fastener	Spec. No.	Grip In.	Average Number of Cycles Applied	Maximum Cyclical Slip of a Spec.		Number of Main-Plate Failures In Joints	Number of Joints Tested
				Initial	Final		
Bolt ASTM-A325	A2B	2-1/16	1,754,738	0.002	0.001	Three	4
	A3B	3-1/16	573,642	0.002	0.002	Three	4
Hot-Driven Rivet	A1H	1-3/16	1,216,610	0.010	0.022	Two	4
	A2H	2-1/16	722,918	0.002	0.006	Two	4
ASTM-A141	A3H	3-1/16	345,481	0.002	0.002	Two	2

TABLE 4. SUMMARY OF FATIGUE TESTS FOR SERIES C, D, AND E.
STRESS CYCLE: 0 TO 27,000 PSI. TENSION

Series	Type of Rivet	Spec. No.	Grip In.	Average Number of Cycles Applied	Maximum Cyclical Slip of a Spec.		Number of Main-Plate Failures In Joints	Number of Joints Tested
					Initial	Final		
C	ASTM-A141	C1C	1-5/16	586,940			Three	3
	ASTM-A195	C1A	1-5/16	617,047			Two	2
D	ASTM-A141	D4C	4-1/16	361,329	0.002	0.003	Two	2
	ASTM-A195	D4A	4-1/16	1,462,813	0.001	0.001	One	2
E	ASTM-A141	E2C	1-13/16	65,242	0.005	0.005	Rivets Failed	2
	ASTM-A195	E2A	1-13/16	186,541	0.001	0.002	Rivets Failed	2
	ASTM-A195	E3A	2-15/16	255,189	0.004	0.004	Three	3

TABLE 5. AVERAGE SHEAR STRESSES AT FIRST MAJOR
SLIPS FOR JOINTS WITH HOT-DRIVEN RIVETS

Series	Rivet Designation ASTM	Grip In.	Shear Stress At First Major Slip psi.	Shear Stress Clamping Stress*
A	A141	1-3/16	5,800	0.27
	A141	2-1/16	20,000	0.61
	A141	3-1/16	19,000	0.54
C	A141	1-5/16	21,200	1.22
	A195	1-5/16	19,800	1.35
D	A141	4-1/16	15,500	0.45
	A195	4-1/16	23,000	0.49
E	A141	1-13/16	14,500	0.49
	A195	1-13/16	18,800	0.81
	A195	2-15/16	20,000	0.45

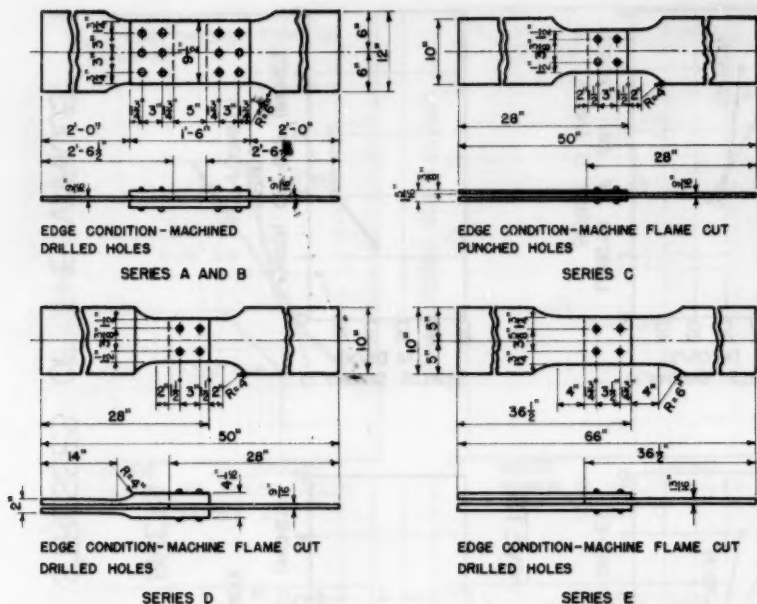
*Shear Stress at first major slip/Initial clamping stress

TABLE 6. AVERAGE EFFICIENCIES OF JOINTS
TESTED IN STATIC TENSION

Series	Type of Fastener	Fastener Designation ASTM	Plate Efficiency %
	Bolts	A325	82.9
A	Hot-Driven Rivets	A141	81.5
	Cold-Formed Cold-Driven Rivets	A141	81.3
	Hot-Formed Cold-Driven Rivets	A141	81.2
	Hot-Formed Cold-Driven Rivets	A141	81.5
B	Hot-Driven Rivets	A141	70.8
C ^(a)	Hot-Driven Rivets	A195	71.3
	Hot-Driven Rivets	A141	83.0
D	Hot-Driven Rivets	A195	82.4
	Hot-Driven Rivets	A141	85.5
E ^(b)	Hot-Driven Rivets	A195	88.0
	Hot-Driven Rivets	A141	85.5

(a)Specimens had punched holes. All other
specimens had drilled holes.

(b)Specimens had a t:s:b ratio of 1.00:1.26:1.83.
All other specimens had a t:s:b ratio of 1.00:
0.75:1.50.

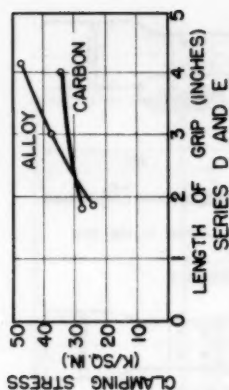
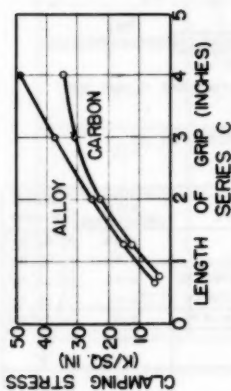
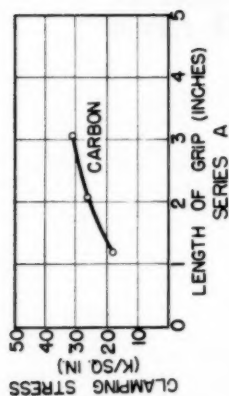


SERIES	TENSION: SHEAR: BEARING RATIO	AREA, SQ. IN.			TYPES OF FASTENERS *	FASTENER, ASTM DESIGNATION	LENGTH OF GRIP
		TENSION	SHEAR	BEARING			
A	100: 0.75: 1.57	3.97	5.30	2.53	HIGH-TENSILE BOLTS	A325	18 25/32"
					HOT-DRIVEN RIVETS	A141	18 25/32"
					COLD-FORMED COLD-DRIVEN RIVETS	A141	18 25/32"
					HOT-FORMED COLD-DRIVEN RIVETS	A141	18 25/32"
B	100: 0.76: 1.59	4.03	5.30	2.53	HOT-FORMED COLD-DRIVEN RIVETS	A141	18 25/32"
C	100: 0.75: 1.51	2.67	3.54	1.69	HOT-DRIVEN RIVETS	A141 A195	18" 18"
D	100: 0.75: 1.51	2.67	3.54	1.69	HOT-DRIVEN RIVETS	A141 A195	4 1/2" 4 1/2"
E	100: 1.26: 1.83	4.47	3.54	2.44	HOT-DRIVEN RIVETS	A141	18"
						A195	18 25/32"

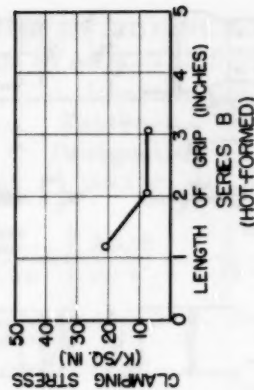
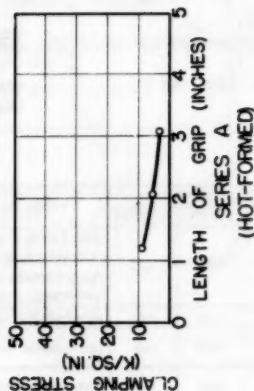
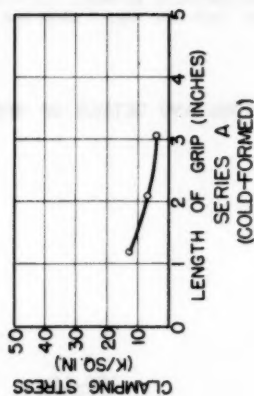
* NOMINAL DIAMETER OF ALL FASTENERS, 3/4 INCH.

DIAMETER OF ALL HOLES: 13/16 INCH, EXCEPT 25/32 INCH FOR SERIES B.

FIGURE 1: DIMENSIONS AND DETAILS OF SPECIMENS



HOT-DRIVEN RIVETS



COLD-DRIVEN RIVETS

FIGURE 2: AVERAGE CLAMPING STRESSES OF THE VARIOUS KINDS OF RIVETS

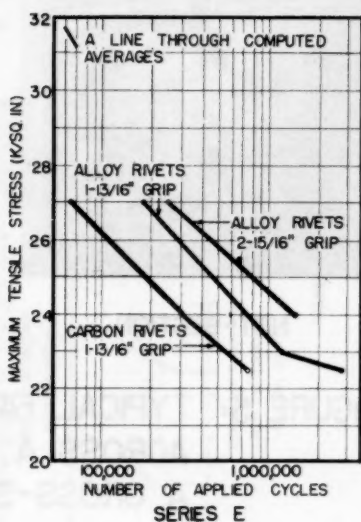
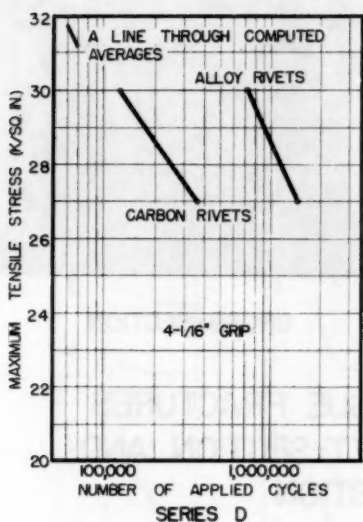
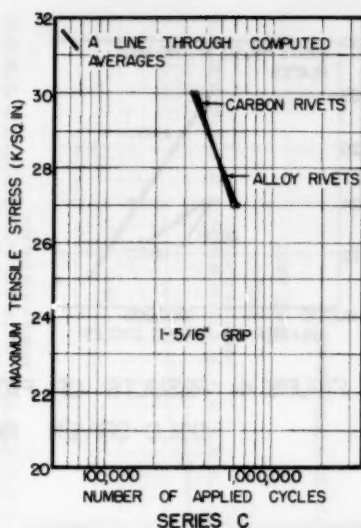
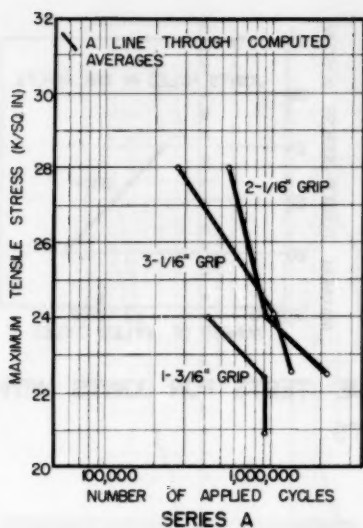


FIGURE 3: RESULTS OF FATIGUE TESTS FOR JOINTS WITH HOT-DRIVEN RIVETS

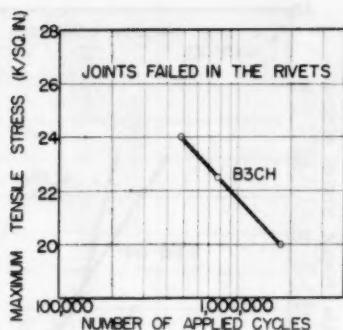
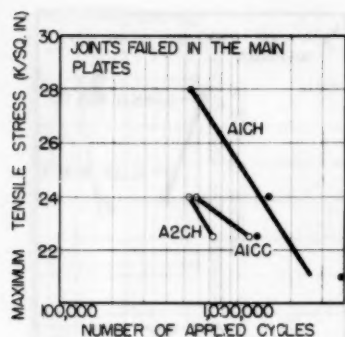


FIGURE 4: RESULTS OF FATIGUE TESTS FOR JOINTS WITH COLD-DRIVEN RIVETS



NET-SECTION



GROSS-SECTION

FIGURE 5: TYPICAL FATIGUE FRACTURES ACROSS A NET-SECTION AND A GROSS-SECTION

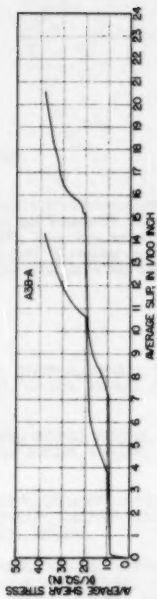
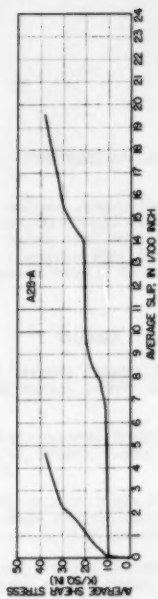
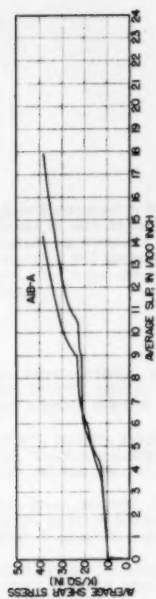
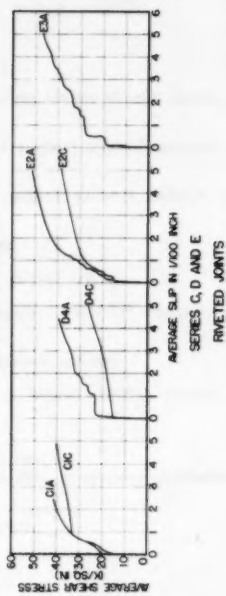
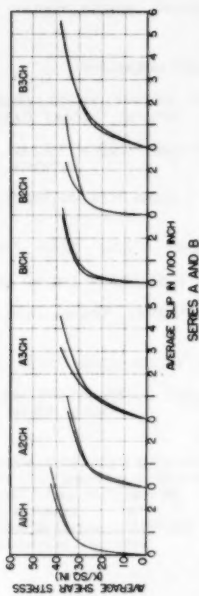
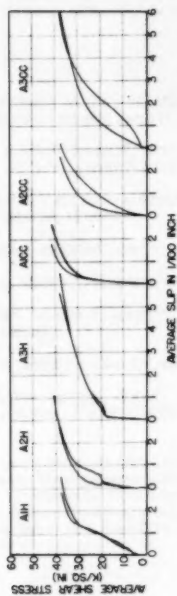


FIGURE 6: SHEAR STRESS VERSUS SLIP FOR JOINTS TESTED IN STATIC TENSION



PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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AUGUST: 230(HY), 231(SA), 232(SA), 233(AT), 234(HW), 235(HW), 237(AT), 238(WW), 239(SA), 240(IR), 241(AT), 242(IR), 243(ST), 244(ST), 245(ST), 246(ST), 247(SA), 248(SA), 249(ST), 250(EM)^a, 251(ST), 252(SA), 253(AT), 254(HY), 255(AT), 256(ST), 257(SA), 258(EM), 259(WW).

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OCTOBER:^b 290(all Divs), 291(ST)^d, 292(EM)^a, 293(ST)^a, 294(PO)^a, 295(HY)^a, 296(EM)^a, 297(HY)^a, 298(ST)^a, 299(EM)^a, 300(EM)^a, 301(SA)^a, 302(SA)^a, 303(SA)^a, 304(CO)^a, 305(SU)^a, 306(ST)^a, 307(SA)^a, 308(PO)^a, 309(SA)^a, 310(SA)^a, 311(SM)^a, 312(SA)^a, 313(ST)^a, 314(SA)^a, 315(SM)^a, 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

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MARCH: 414(WW)^d, 415(SU)^d, 416(SM)^d, 417(SM)^d, 418(AT)^d, 419(SA)^d, 420(SA)^d, 421(AT)^d, 422(SA)^d, 423(CP)^d, 424(AT)^d, 425(SM)^d, 426(IR)^d, 427(WW)^d.

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JUNE: 444(SM)^e, 445(SM)^e, 446(ST)^e, 447(ST)^e, 448(ST)^e, 449(ST)^e, 450(ST)^e, 451(ST)^e, 452(SA)^e, 453(SA)^e, 454(SA)^e, 455(SA)^e, 456(SM)^e.

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a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.

b. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.

c. Discussion of several papers, grouped by Divisions.

d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.

e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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